COMMENTARY ON REPORTS ON THE SMOKE MANAGEMENT SYSTEM IN THE CENTRAL SHOPPING MALL IN TAIPEI

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Over the last 8 to 9 years, the present author has seen it as part of his contribution to fire science and technology to point out difficulties with thermocouple temperature measurements in combustion experiments. The culmination of this is an ASTM chapter [1] published earlier this year. Previously he had contributed a number of short notes to journals pointing out that in work described in published articles insufficient attention might have been paid to thermocouple measurements [e.g. 2] and had also alerted industrial users of thermocouples to potential difficulties by means of a number of articles in trade journals [e.g. 3,4].

The present author has no wish to gain a reputation for being repetitious in this regard. Nevertheless, the article by Yang and Yang [5] in a recent issue of this journal reports thermocouple usage which, as far as it can be understood from the brief account given, is so wide open to criticism that comment and clarification are required for the benefit of present and future readers.

First of all however, there is in [5] a fundamental point other than the temperature measurements which is also very uncertain. In the interpretation of results, the quantity Q – rate of heat release by a gasoline pool fire used to simulate an accidental fire – is used. The authors use a pan of 45 cm diameter to contain the gasoline and, once it is ignited, determine the weight loss. This can be multiplied by the calorific value to give the heat release rate. On page 37 of the article, the mass loss rate is given as 0.005 kgs⁻¹ in the 45 cm pan. This means that the mass loss rate per unit area is:

\[ \frac{0.005}{(\pi \times 0.225^2)} = 0.03 \text{ kg m}^{-2}\text{s}^{-1} \]

It is very widely known [e.g. 6,7] that almost all hydrocarbon pool fires burn at about 0.1 kgm⁻²s⁻¹. Possible exceptions are:

(i) Certain oxygenates

(ii) Fires in a pan such that conditions are laminar rather than turbulent. However, a 45 cm pan is quite large enough for conditions to be turbulent. Laminar conditions apply to pans of 10 cm diameter or smaller.

Gasoline is expected to conform to the 0.1 kgm⁻²s⁻¹ rule. The fact that the value in the paper under discussion is a factor of three lower needs looking into, especially as it is the basis of the heat release rates which feature so centrally in the paper. Fig. 4 in the paper shows different mass burning rate for gasoline in a 45 cm pan and this also is difficult to understand. In fact, it might arguably have been acceptable to reviewers of the work for the authors of [5] to dispense with the weighing of the pan and assume a mass loss rate of \((0.1 \pm 0.025)\) kgm⁻²s⁻¹ and to calculate the heat release rate directly from this. The authors of [5] could have invoked several references in support of such an approach.

Turning now to the thermocouples, information as to their type (K, J, N, R etc.) is missing and this is a pity as such information is helpful to a reader. However, positively necessary in evaluating the precision of the measurements is knowledge of the thermocouple tip width or, if it is sheathed, the sheath diameter. This too is missing from [5]. Also necessary yet absent is information regarding the temperature of any solid surface of which the thermocouple might have ‘sight’ which in the application under discussion means the walls of the enclosure containing smoke.

Turning to Fig. 5, which shows thermocouple readings at various heights from a fixed reference level, there is a rise from 20 to 28.6 K over a 15 m change in height. This can be analysed in heat balance terms as follows. In the absence of information, a value of 1 mm – which might apply to a bare-wire or a sheathed thermocouple – will be used for the tip dimension, and it will be taken that all eleven thermocouples readings from which feature in the figure had this diameter. It has been shown [1] that whether convection to the tip is forced, natural or both the correlation:

\[ \text{Nu} = 2.7 \]

where Nu is the Nusselt number (= hd/k, where h is the convection coefficient in Wm⁻¹K⁻¹, d is the thermocouple tip diameter and k the thermal conductivity of air) applies. For a 1 mm thermocouple, putting \(k = 0.03\) Wm⁻¹K⁻¹:

\[ h = 80 \text{ Wm}^2\text{K}^{-1} \]
Before proceeding, we note first that the intrinsic uncertainty in the thermocouple readings, due to thermoelement inhomogeneity, is ± 2.2 K at such temperatures for most base metal thermocouples. We also note that, as it is standing in smoke, the thermocouple tip is likely to have a high emissivity through particle deposition so that to treat it as a black body is reasonable. The interested reader can easily repeat the subsequent calculations using an emissivity of say 0.8 to 0.9. Imagine that at height 65 m when the thermocouple is reading 28.6 °C (301.6 K), the wall temperature is at 293 K. The radiation error is then:

\[ (5.7 \times 10^{-5}/80) \times (301.6^4 - 293^4) = 0.6 \text{ K} \]

so the tip is actually at 29.2 °C plus or minus the other errors. This reading could actually mean that the tip temperature is 31.4°C because of the calibration uncertainty already mentioned. Considering now the thermocouple at 50 m height which reads 20°C (293 K), if the wall temperature is fairly constant at 293 K, there will not be radiation effects with this. However, the 20°C could actually mean 17.8°C without anything being amiss in terms of thermocouple calibration. The value of ΔT given on the diagram as 8.6 K is thereby increased to:

\[ 31.4 - 17.8 = 13.6 \text{ K} \]

a difference of almost 60%. The above calculations, though incorporating arbitrary values for the tip diameter and wall temperature and ‘worst case’ for the thermocouple calibration, nevertheless show that the value of 8.6 K for ΔT cannot be accepted with confidence. The matter of wall temperature must be addressed. Also there are possible errors due to thermocouple wear and tear, especially if they have been bent, so that the ± 2.2 K used above is too low a margin. One must also consider instrumentational effects; for example, an internal cold junction compensation device is usually only reliable to about plus or minus half a degree. In fact, it is not inconceivable that the walls are hotter than the smoke in which case the thermocouples are receiving radiation from them and reading high. Much more information and reasoning are required in the paper under discussion. Further points of comment will follow.

In Fig. 7, a thermocouple response signifying stages in smoke development is plotted with time as the abscissa. This surely requires that a reader be informed of the time constant (τ, units seconds) of the thermocouple. For a 1 mm diameter Type K thermocouple at the convection coefficient calculated above, it is about 7 seconds.

The points needing clarification are then the mass loss rate of gasoline and hence the heat release rate in the simulations and the thermocouple precision. A final point is the assertion that ‘God himself validated the performance of the smoke management system’, a reference to an actual fire, started by arsonists, in which the system worked as expected. In the insurance world, the term ‘Act of God’ is usually reserved for factors outside all human control such as lightning strikes, so the work of arsonists would not be so classified. The present author questions the appropriateness of the invocation of a divine agency in a modern scientific report.

REFERENCES